AAL-TDR-63-36

TREATMENT OF UNDILUTED HUMAN WASTE BY THE ACTIVATED SLUDGE PROCESS

TECHNICAL DOCUMENTARY REPORT AAL-TDR-63-36

March 1964

ARCTIC AEROMEDICAL LABORATORY

AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
FORT WAINWRIGHT, ALASKA

Project 8246, Task 8246-1

(Prepared under Cross Service Agreement CSA 61-1 by
D. J. Baumgartner and C. F. Walters
Arctic Health Research Center, U. S. Public Health Service,
Department of Health, Education, and Welfare, Anchorage, Alaska)

ABSTRACT

A laboratory activated sludge system was operated to confirm field investigations which indicated that a 423-gallon recirculating activated sludge system could adequately treat the undiluted human wastes from 10 men for at least six months and provide an effluent acceptable for use as a flushing fluid. In addition, the level and the effects of overloading were noted. The effect of high pH on odor production was observed, and the importance of pH control between 6 and 7 was demonstrated. The feed COD of 44, 000 mg/l (BOD = 21, 000 mg/l) was reduced by about 90 per cent and the estimated water savings for toilet flushing was estimated at greater than 90 per cent.

PUBLICATION REVIEW

Horace F. Drury

HORACE F. DRURY
Director of Research

TREATMENT OF UNDILUTED HUMAN WASTE BY THE ACTIVATED SLUDGE PROCESS

SECTION 1. INTRODUCTION

Many of the U. S. Air Force radar sites in Alaska are faced with problems of water supply, as well as of waste disposal. Superimposed on the problems of obtaining, treating, and storing water and of collecting and disposing of wastes at a 100-man installation in extremely cold climates are the difficulties caused by the operating requirements of the radar site. In many cases the radar unit is completely separate from the main operating base of the installation; frequently it is located on a nearby hilltop and is maintained by a complement of ten men. In order to reduce construction and maintenance costs, water is carried from the main camp to the hilltop in tank cars, if roads are present, or in barrels on a tramway. Water is rationed, and the use of flush toilets constitutes a major water use. If flush toilets are employed, either a heated sewer from the hilltop to the main camp or a separate sewage treatment unit at the hilltop camp must be provided. The pit privy is ruled out because of permafrost and the long periods of cold weather. The "honey-bucket" method of waste disposal, common at other places in Alaska, is ruled out because of the problem of ultimate disposal. Some of these top camps are provided with heated septic tanks and a heated effluent line for a short distance from the building. At that point the septic tank effluent is discharged to the ground. Although this system operates satisfactorily for waste disposal, the problem of water supply still exists, since large quantities of water are required for the flush toilets.

The Arctic Health Research Center was requested by the Air Force to investigate possible solutions for the problems of water supply and waste disposal at these radar sites. One of the initial proposals concerned the possibility of using a waste treatment process which provides an effluent suitable for reuse as a toilet flushing liquid. Primary consideration was that such a waste disposal system should provide trouble-free and maintenance-free service for ten men for at least six months. The surveillance required and first cost ruled out use of such a system in two to four man installations, and the 80 to 100 man installations could justify the cost required for a more elaborate water supply system and a conventional waste disposal system.

Similar systems have been investigated previously. In 1951 Perry

reported on a 240-gallon household activated slu... ystem which satisfactorily treated the sewage from about four persons ... a period of eight months. However, this was a flow-through system in which no attempt was made to apply any water conservation principles. No data on BOD removal were provided. Bloodgood (1952) reported on the same system employing recirculation for flushing and adding water for make-up only. Again no BOD removal data were provided. Rigby (1954) investigated the principle using various water uses but no measure of organic removal efficiency was provided. In 1952, Coulter et al reported on a no-effluent, recirculating system employing a 55-gallon drum as the treatment tank. The results were unsatisfactory. The authors estimate that the unit received the wastes from the equivalent of about three men.

Work performed at the U. S. Naval Civil Engineering Laboratory, Port Hueneme, California, has been reported by W. R. Nehlsen (in Navy publications intended for "Official Use Only"). This work included investigations on both small and large (nearly conventional) water use systems. The actual overflow rates were not reported. The organic loadings varied from three men/100-gallon tank to 20 men/200-gallon tank during the experimental period which lasted from two to four months. The results were unsatisfactory.

In 1958 the National Research Council reported on individual household aerobic sewage treatment systems in which criteria for design and performance were presented. For closed systems, that is, systems with no effluent discharge, the report stated that the aeration compartment should have a volume "not less than 160 gallons per pound of influent five-day BOD applied per day," and for flow-through systems the recommended volume was "400 gallons per pound of influent five-day BOD per day." The report also recommended that aeration "shall not be less than 1,000 cubic feet per lb. of influent five-day BOD." In order to compute the volume of the tank and the quantity of air required, the report suggested using 0.167 pounds of five-day BOD per capita per day with an increased safety factor of 50 per cent to allow for unusual conditions, such as the presence of guests. In evaluating performance, it was suggested that the effluent characteristic should not exceed 50 mg/l of five-day BOD and 150 mg/l of suspended solids, and the pH should be maintained from 6.5 to 8.5. No consideration was given the fact that closed systems, or systems which employ major water conservation features such as recirculation of the treated effluent, produce considerably less volume of effluent. Even though the BOD concentration may be much greater than 50 mg/l, the total weight of organic material discharged in the effluent daily may be significantly less than that discharged in the flow-through system adhering to the restriction of 50 mg/l of BOD. The same reasoning should apply to the suspended solids concentration.

The report concluded with a list of needed research projects pertaining to this system, e.g. (1) determination of reduction in BOD, COD, suspended

solids, and micro-organisms of public health significance under different loading conditions; (2) simplification of operation, design, and maintenance for use in cold weather areas; and (3) bacterial reductions provided by further treatment, such as lagoons or filters.

Walters and Anderegg (1962) reported on several field tests of recirculating systems in Alaska which conformed essentially to the diagrammatic scheme shown in Figure 1.

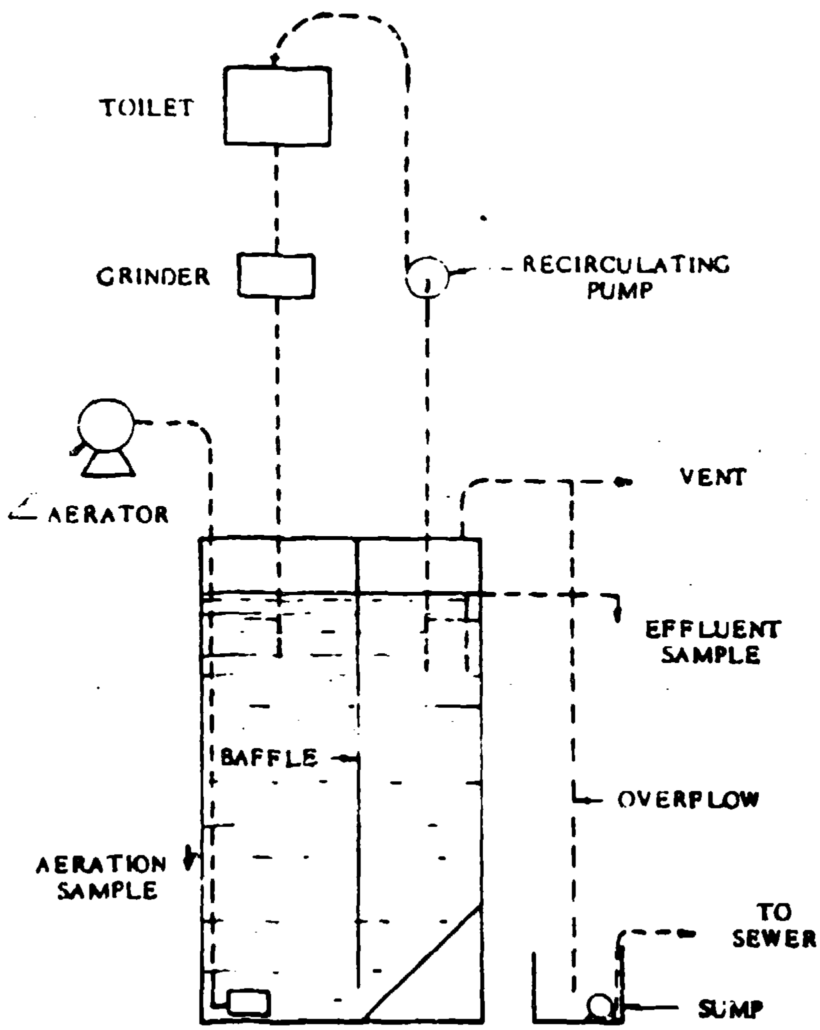

FIGURE 1

Aerobic Recirculating Waste Treatment Unit

The characteristics of these systems are tabulated below:

TABLE I

Unit	Capacity Total	Gallons Aeration	Water Use* Gal/man/day	Loading Men	Length of Run Days	Remarks
Tatalina I radar site	423	317	0	6-8	60	Odors
Tatalina II radar site	423	317	0.2	6-8	350	Odors
Sparrevohn radar site	423	317	0.8	3	700	No Odors Excellent Performance
Anchorage I	423	317	0.9	8-9 14 hrs/day	180	No Odors Excellent Performance

*Overflow plus evaporation

These investigations indicated that the 423-gallon system should be adequate for treating the wastes from 10 men for six months and provide an acceptable fluid for flushing. However, it was considered desirable to determine whether the water use could be reduced, and the possible effect on the system of overloading for brief or extended periods. To this end, a smaller scale laboratory unit was constructed; organic loading was the first parameter selected for study.

SECTION 2. SUMMARY

Laboratory investigations were carried out to confirm the results of field operations which indicated that an aerobic recirculating waste system could, under the proper loading conditions, provide an odor-free and relatively clear effluent which would be satisfactory for a toilet flushing fluid. The laboratory investigations allowed closer control of the operating characteristics, permitting additional qualitative determinations and more frequent

observations of performance. The primary variable studied was the effect of organic loading upon the quality of the flushing fluid. Although consideration was given to the system, the primary measures of acceptance were lack of odors and relatively clear effluent. The results of the laboratory experiments are shown in Table II.

The results indicate that the 423-gallon tank should be capable of treating the waste from 10 men satisfactorily for at least six months if enough dilution is provided by hand-washing sink (estimated to be about 0.75 gpcpd, at which rate a savings in water use for toilet flushing of over 90 per cent could be realized). For odor free performance it appears necessary to maintain the pH below 7.5 and preferably between 6 and 7.

SECTION 3. THE LABORATORY TREATMENT UNIT

A plastic laboratory model of an activated sludge unit was constructed as shown in Figure 2. The wet laboratory air used for aeration was first dried to determine accurately the air flow rate and then bubbled through a flask in order to reduce the evaporation which would otherwise occur in the treatment unit. The overflow from the built-in settling compartment was collected in a graduated cylinder and measured daily. In order to overcome the objection of batch feeding and the problems of continuously feeding a small quantity of liquid, the automatic feeding system shown in Figure 3 was devised. The syringe is filled from the feed reservoir every 30 minutes, when the solenoid is energized. When the timer breaks the circuit the external spring depresses the plunger and forces the desired feed volume into the aeration compartment through a two-way valve. Simultaneously a recirculating pump operates to stimulate flushing of the toilet which in effect recirculates the liquid from the settling chamber to the aeration chamber, thus preventing depletion of dissolved oxygen in the settling area.

On the basis of field experience it was estimated that the systems could handle the waste from approximately 10 men, but in order to obtain background information it was decided to start off the laboratory unit at a simulated load of five men. The average daily load of waste per person was estimated to be 0.25 pounds of COD, or 567 gram COD/day for a five-man loading. With an actual volume of 423 gallons the influent COD concentration was calculated to be $\frac{567 \times 1000}{423 \times 3.785} = 354$ mg/l/day.

Applying this concentration to the 4.5 liter laboratory unit, the feed rate for the smaller systems would be $354 \times 4.5 = 1590$ mg/day.

Assuming a prototype overflow rate of 0.6 gal/man/day, the theoretical detention time for a five-man loading would be $\frac{423}{5 \times 0.6} = 141$ days. Applying

TABLE II

Time, Days	LOADING: Laboratory Unit: Organic MgCOD/l/hr	LOADING: Laboratory Unit: Volumetric (overflow rate) ml/day	LOADING: Extrapolation to Field Use: Organic men/423 gal	LOADING: Extrapolation to Field Use: Volumetric (overflow rate) gal/man/day	Average pH	Performance
0 - 99	15	55	5.1	1.0	7.1	Good
100 - 199	31	60	11	0.52	6.0	Acceptable
200 - 240	49	54	17	0.30	8.2	Poor

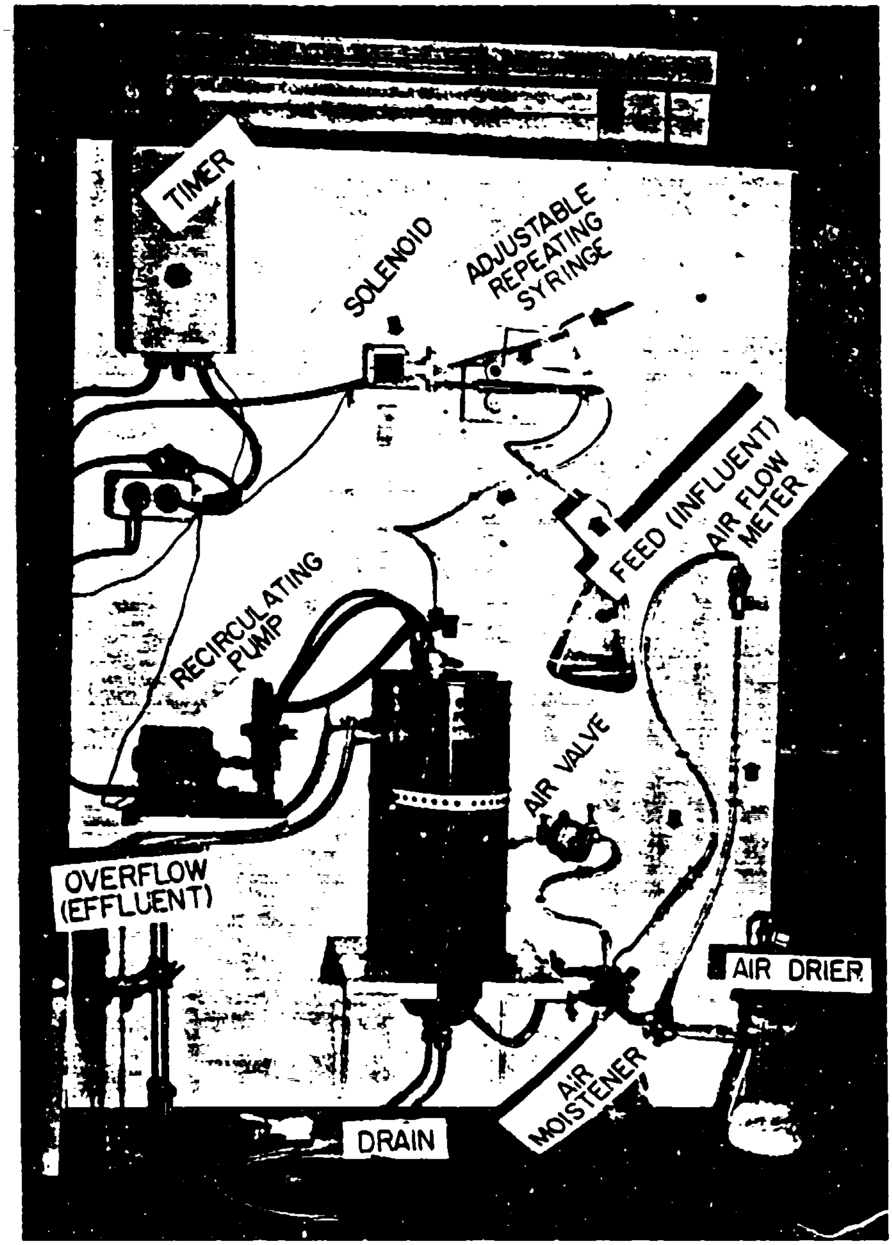

FIGURE 2

Laboratory Unit

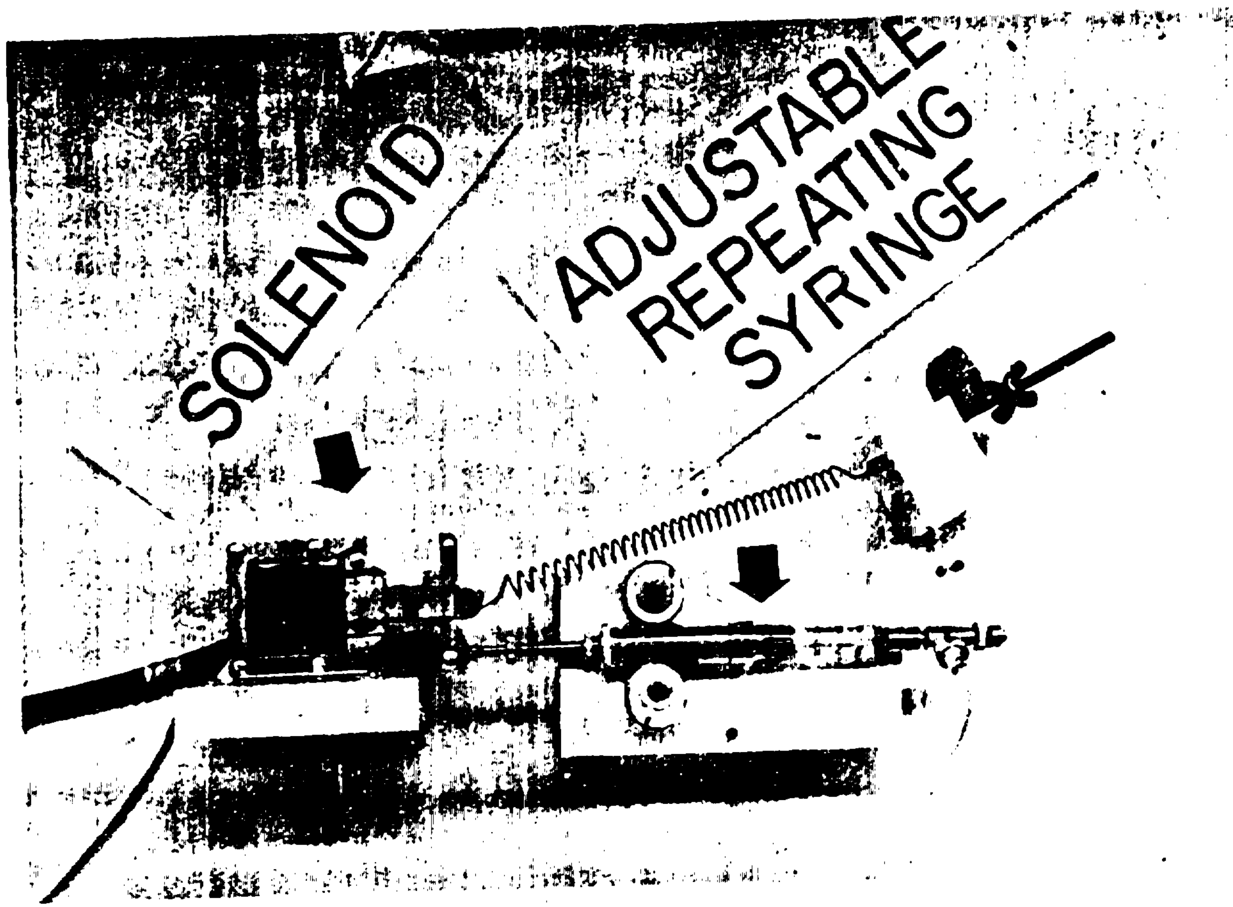

FIGURE 3

Feeder

this to the laboratory unit, the overflow rate would be $\frac{4,500}{141}$ = 32 ml/day. However, to make up for the evaporation which occurs in the laboratory unit (determined to be about 40 ml/day) the hydraulic loading was selected as 72 ml/day. This dictated that the feed concentration should be $\frac{1,590}{72}$ x 1000 = 22,100 mg/l. The 72 ml/day was fed uniformly over 24 hours at the rate of 1.5 ml each half hour. The feed, formulated to correspond in organic strength to human waste, consisted of (a) 19 grams nutrient broth, (b) 2 grams urea, (c) 5 grams dibasic potassium phosphate, and (d) tap water to 1 liter. After dilution, the solution was autoclaved in order to prevent bacterial growth and hence possible clogging of the feeding system by microbial solids.

The aeration rate in the Anchorage field unit was maintained at 1.22 cfm per thousand liters of aeration capacity or 34.5 cc per minute per liter. The aeration capacity of the laboratory unit was four liters; hence the amount of air required was 138 cc per minute. Because of the design of the unit and the size of the diffuser available, this aeration rate did not produce enough turbulence and it was necessary to increase the aeration rate to 400 cc/minute.

SECTION 4. ANALYTICAL PROCEDURES

Determinations of the COD on the feed solution and on the mixed liquor were performed twice weekly in accordance with Standard Methods (APHA, 1960) using silver sulphate as a catalyst. COD values were also obtained for filtered mixed liquor samples and less frequently for the supernatant in the settling compartment. The residue obtained from the filtered sample was used to determine the mixed liquor suspended solids. Filtration was accomplished by the use of a membrane filter as described by Engelbrecht and McKinney (1956). The BOD was determined by the standard dilution technique and by the use of a Warburg respirometer.

SECTION 5. RESULTS

During the first 99 days of operation the feed COD averaged 22,000 mg/l. Mixed liquor suspended solids increased steadily for the first 30 days to a value of almost 3,000 mg/l and stayed at that level thereafter (Figure 4). During the same period the effluent suspended solids increased rapidly to a level of 500 mg/l. Subsequent fluctuations were due primarily

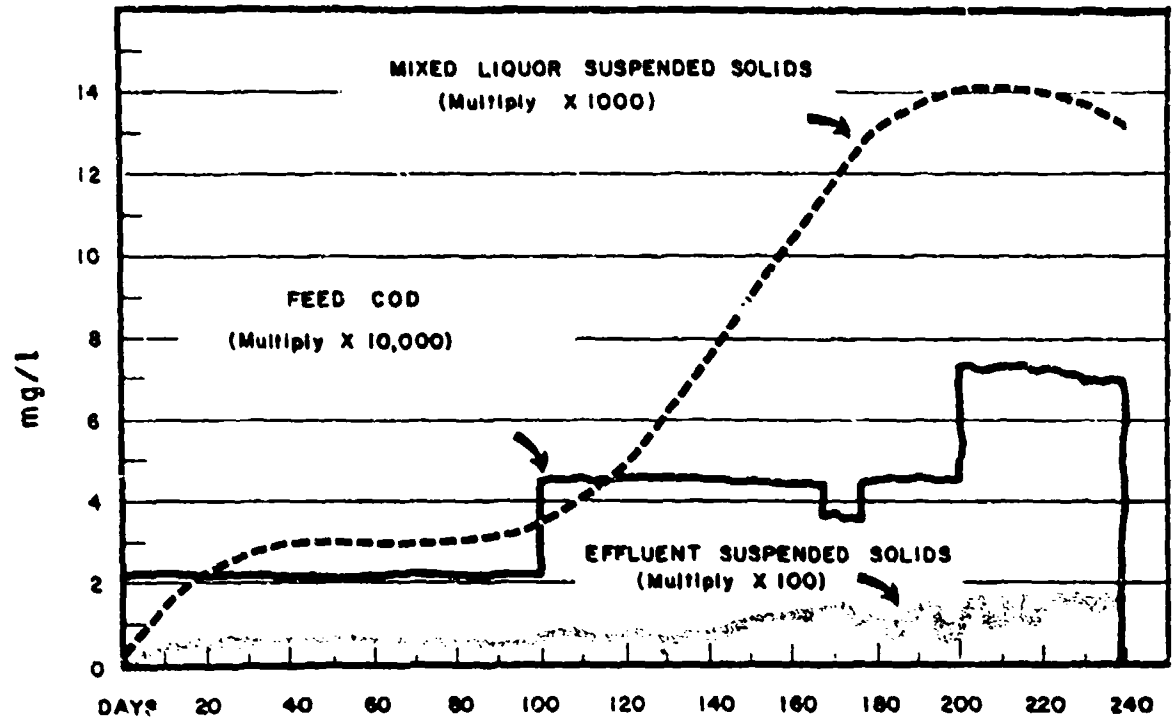

FIGURE 4

Effect of Organic Loading on Suspended Solids

to sporadic disturbances of the sludge blanket by aeration surges. The filtered mixed liquor COD (Figure 5) increased rapidly during the first 40 days and began to level off about 1,400 mg/l, after which time the COD fluctuated rather widely and appeared to show a downward trend. The pH (Figure 6) fluctuated between 6 and 8.5, averaging 7.1, and appeared to be decreasing at the end of the first 100 days. The overflow rate appeared to be much closer to 60 ml/day rather than the 32 ml/day originally intended. During the first 100 days there was no offensive odor production nor was there a noticeable foaming problem.

On the 100th day the feed concentration was nearly doubled with an almost immediate rise in the suspended solids concentration as well as a general upturn in the filtered mixed liquor COD. The pH remained fairly steady around 6. A noticeable fluctuation in effluent suspended solids occurred during this period. After ten days of operation at the simulated feed rate of 10 men, foaming became noticeable in the aeration compartment and it became necessary to add anti-foam (Dow Corning Anti-foam AF Emulsion) as part of the feed. The silicone anti-foam was used at a concentration of 1 gram per liter of feed. Since the overflow rate for the ten-man load was closer to the design rate than the five-man rate, the hydraulic loading of 72 ml/day was not changed.

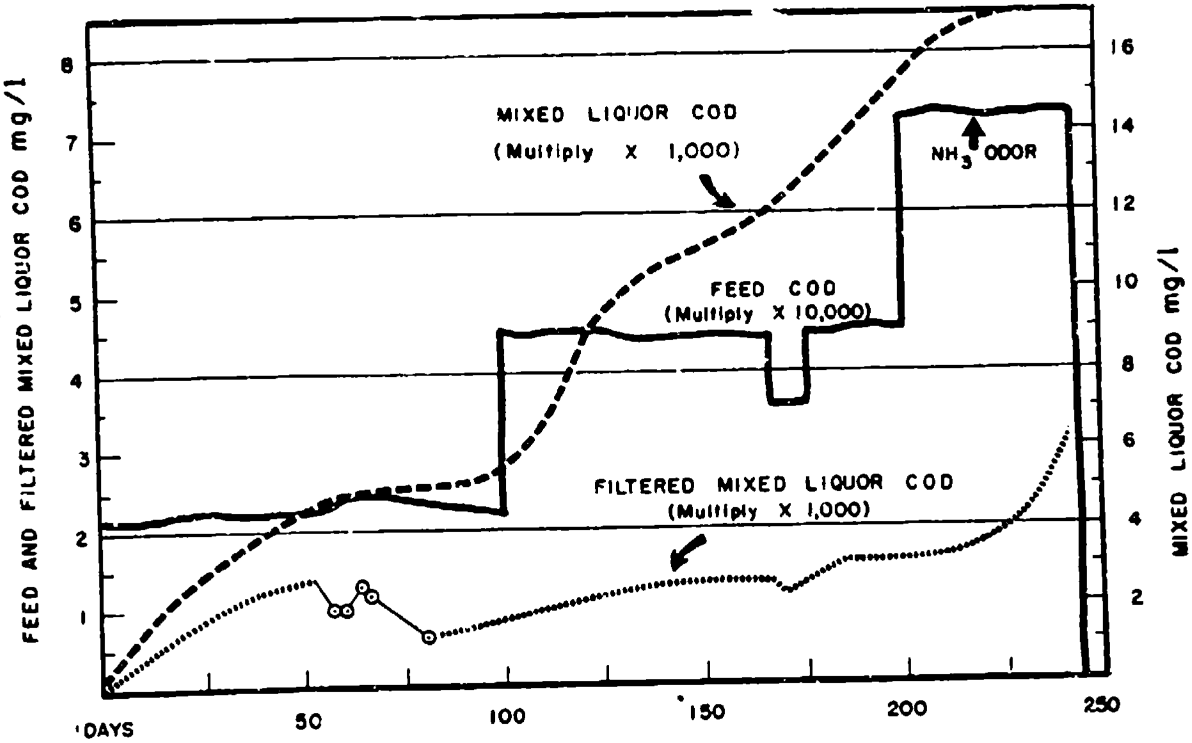

FIGURE 5

Effect of Organic Loading on Removal of Organics

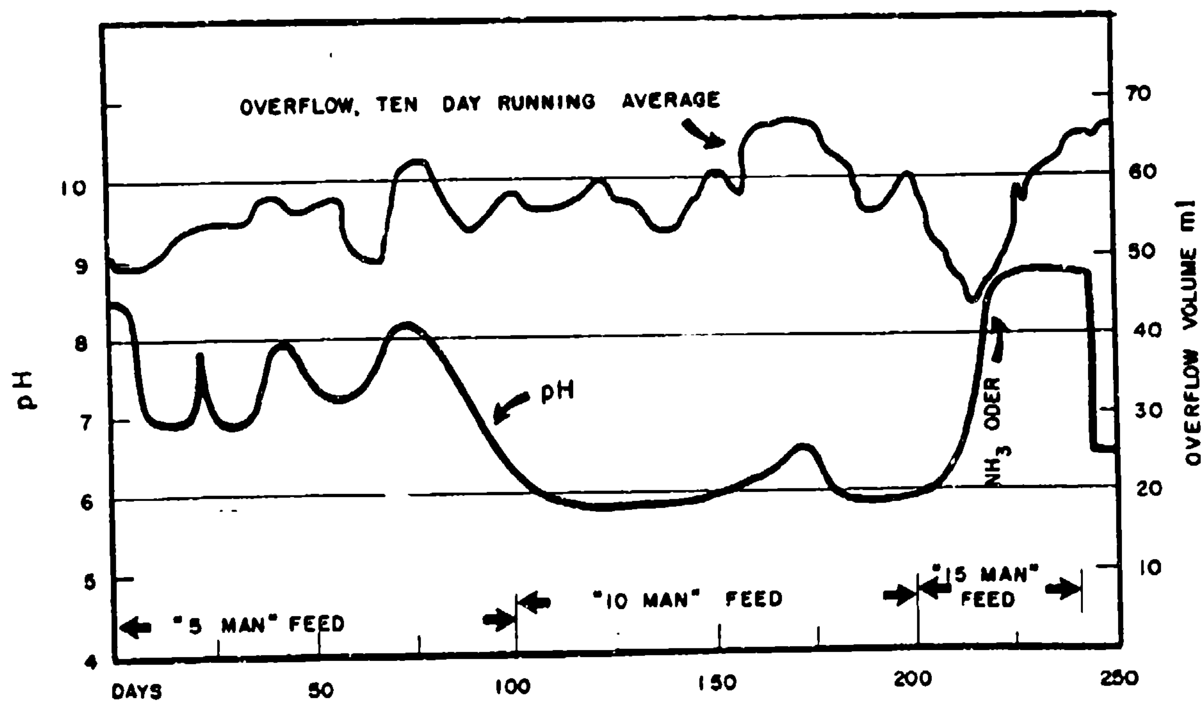

FIGURE 6

Variation of pH and Overflow Rate

On the 200th day of operation the feed concentration was increased to approximately 75,000 mg/l COD to simulate the load of 15 men. On the 205th day foaming again became a problem, and odor production was evident. The odors were primatily those associated with anaerobic activity. On the 225th day the aeration rate was tripled, but except for increased foaming this appeared to have no effect on the system and the odors persisted. After 240 days of operation, feeding was suspended and aeration continued for five days during which time the pH remained high and odors continued. When the pH was lowered to 6.5 using 1:10 sulphuric acid, the ammonia odor was no longer noticeable. The test was then terminated.

During the course of laboratory work several tests were made of the oxygen uptake rate of the mixed liquor in order to (1) determine the effect of the high feed doses, (2) compare the oxygen uptake rate with the mixed liquor from the Anchorage field unit, (3) determine the effect of anti-foam on oxygen uptake, and (4) compare the long-term Warburg oxygen uptake against the standard dilution technique for BOD. These data are shown in Figures 7 through 11 and in Table III, which compares analytical parameters as determined by various methods.

NOTES

(1) MIXED LIQUOR STARVED 24 HRS.
(2) MIXED LIQUOR SUSPENDED SOLIDS = 2500 mg/l
(3) MIXED LIQUOR STARVED FILTERED COD = 960 mg/l
(4) MIXED LIQUOR UNSTARVED FILTERED = 930 mg/l
(5) 23RD DAY OF OPERATION
(6) ANTIFOAM CONCENTRATION = 500 mg/l

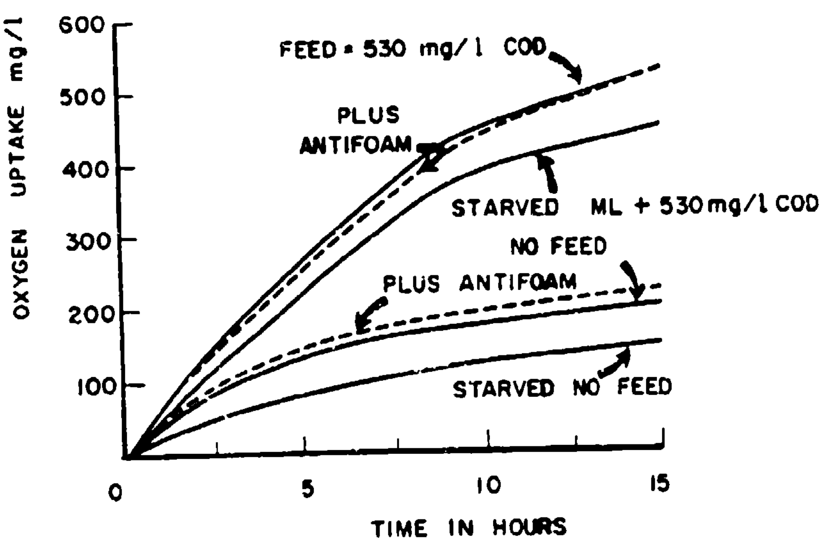

FIGURE 7

Effect of Starving and Anti-Foam on Oxygen Uptake Rate at 30° C of Laboratory Mixed Liquor

NOTES

(1) MIXED LIQUOR STARVED 24 HRS.
(2) MIXED LIQUOR SS = 2300 mg/l
(3) 23RD DAY OF OPERATION

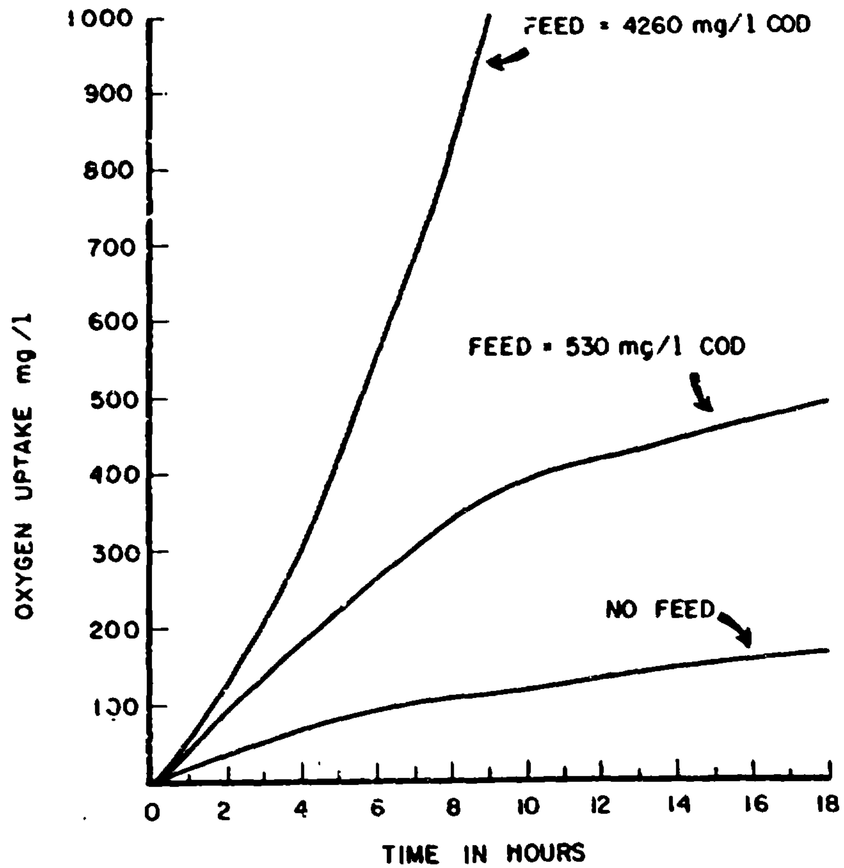

FIGURE 8

Oxygen Uptake Rate at 30° C for Laboratory Mixed Liquor During Various Feeding Conditions

NOTES

(1) BOTH MIXED LIQUORS STARVED 24 HRS.
(2) 88TH DAY OF OPERATION FOR LAB UNIT

DATA

	LAB UNIT	FIELD UNIT
SUSPENDED SOLIDS	2920 mg/l	1125 mg/l
FILTERED COD	300 mg/l	270 mg/l

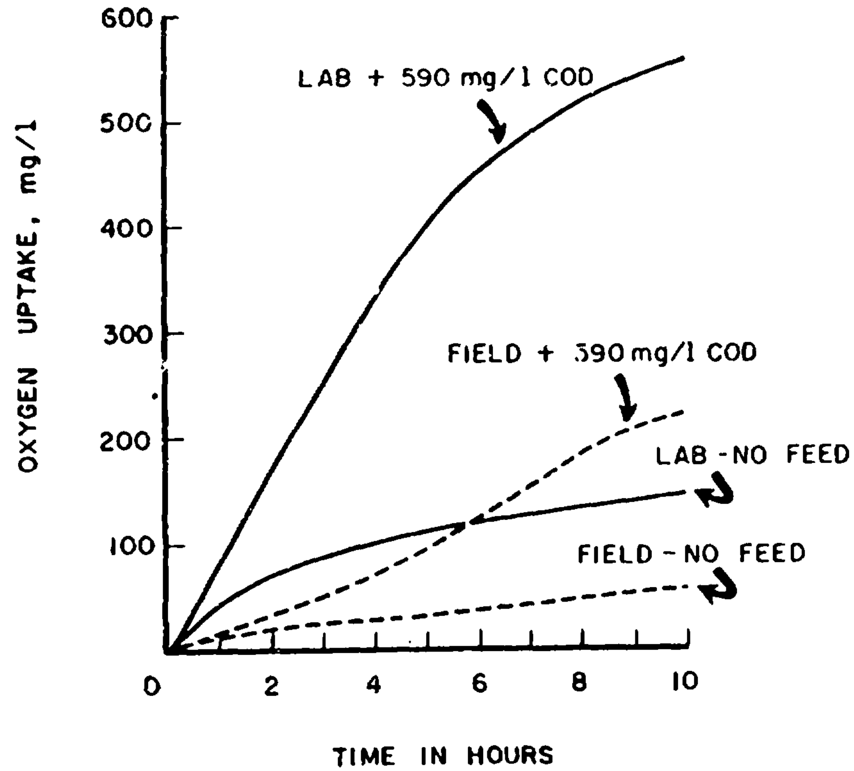

FIGURE 9

Comparison of Oxygen Uptake at 30° C by Laboratory Mixed Liquor and Anchorage Field Unit Mixed Liquor

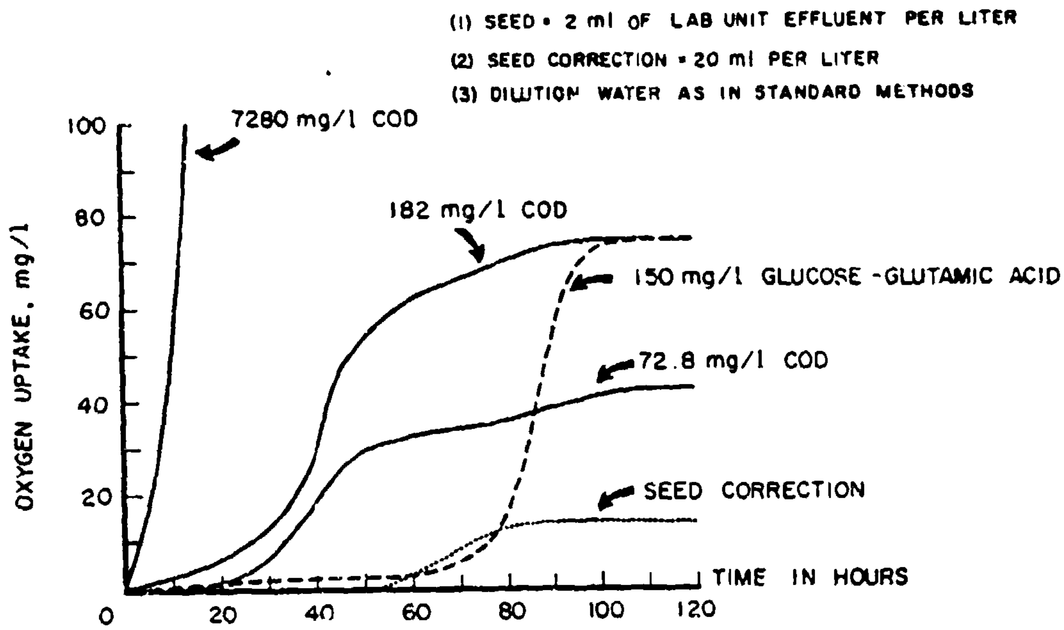

FIGURE 10

Determination of 5 Day 20° C BOD for Various Feed Concentrations Using Warburg Respirometer

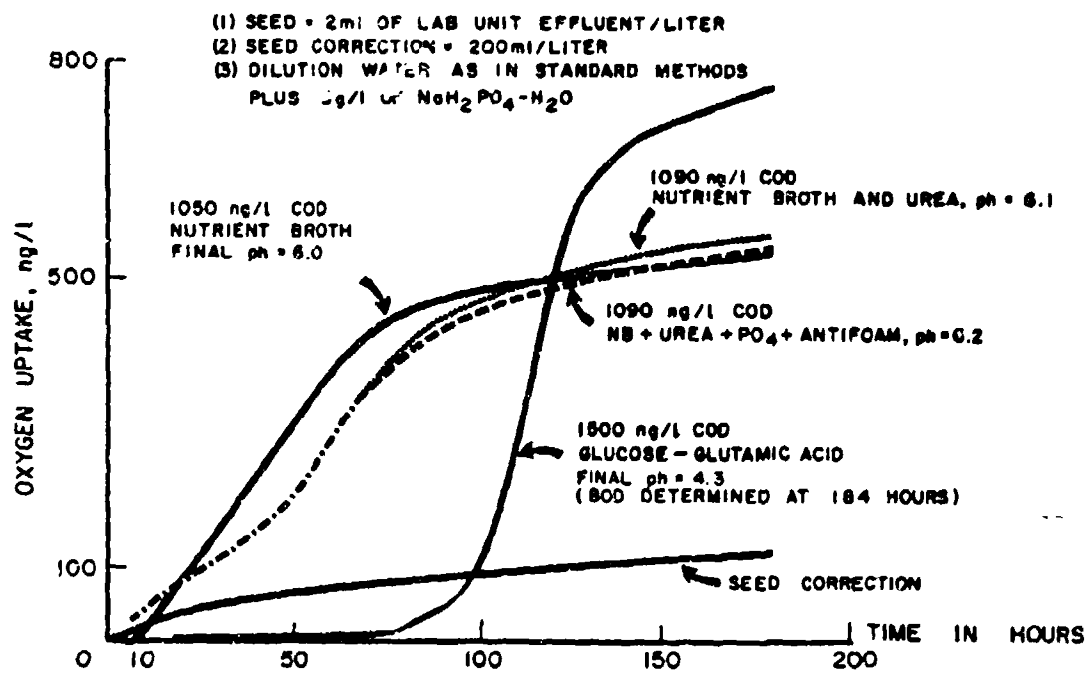

FIGURE 10

Determination of 5 Day 20° C BOD for Feed Constituents Using Warburg Respirometer

TABLE III

SUBSTRATE	COD mg/l	Dilution BOD mg/l	WARBURG, BOD, mg/l (final pH) Lab Seed	WARBURG, BOD, mg/l (final pH) Settled Sewage Seed
Nutrient Broth	42,000		20,000 (6.0)	23,000 (6.5)
NB & Urea	43,700		21,000 (6.1)	24,000 (6.6)
NB & U & PO_4 & Anti-foam	43,500		20,000 (6.2)	24,000 (6.7)
Urea	1,390		50 (6.6)	110 (6.6)
Urea & PO_4 & A.F.	1,270		200 (7.2)	
Anti-Foam	390		150 (6.1)	210 (5.7)
Glucose & Glutamic Acid	6,050		3,100 (4.3)	
Glucose & Glutamic Acid	306	125	150	
NB & U & PO_4 & Anti-Foam	72,800	26,000	30,000	
Unfiltered Mixed Liquor	17,000	210		
Unfiltered Mixed Liquor	11,400		510	
Filtered Mixed Liquor	1,870		510	

SECTION 6. DISCUSSION

Five-man Loading

During the first 100 days of operation when the feed rate simulated a loading of five men, the evidence indicates that the system reached a practical degree of equilibrium as shown by the steady concentration of 3,000 mg/l of suspended solids from the 40th to the 100th day. Admittedly the pH data and the filtered mixed liquor COD data would not support this conclusion. The authors feel, however, that the trend at the end of the period of observation indicates that the primary objective (acceptable performance for a period of 180 days) would have been achieved if the simulated five-man loading rate had been continued for another 80 days. The continuation of this trend for the next 100 days at double the loading rate supports this conclusion. The maximum concentration of COD in a filtered sample of mixed liquor was less than 1,500 mg/l, while the average feed concentration was 22,000 mg/l. This represents an efficiency of removal from solution of 93% initial COD. The average filtered mixed liquor COD for the first 100 days is significantly less than 1,500 mg/l; consequently, the average per cent removal would be somewhat higher. (Although not shown on the graphs, data were collected on the filtered effluent COD and, as might be expected, values were identical to the filtered mixed liquor COD.)

The per cent COD removal does not represent a complete measure of the overall organic removal efficiency since much of the organic material is converted into insoluble cellular material, and some suspended solids do leave the system. However, since most regulatory criteria provide a separate standard for the amount of suspended solids in the effluent, and since no effort was being made to determine the efficiency of the laboratory model as a sedimentation basin, the filtered COD was considered the best indicator available of treatment efficiency. The concentration of COD in the mixed liquor without filtration is provided for comparison (Figure 5). The data show some comparison between the build-up in suspended solids and the mixed liquor COD. In fact, throughout the 250 days of observation, the ratio of suspended solids COD to the oven-dry weight of suspended solids averaged 1:3.

Of even greater interest and significance perhaps are the data on oxygen uptake as determined by the Warburg respirometer, which in many respects can be considered to be a Biochemical Oxygen Demand, although differing somewhat from the conventional method of determination. The data shown in Figure 7 point up the fact that the high value for the filtered mixed liquor COD is not necessarily a good indication of the organic material remaining in solution. After starving the mixed liquor for 24 hours an insignificant increase in COD was noticed. The biochemically oxidizable organic matter (as

determined by the difference in oxygen uptake between the unstarved and starved mixed liquor after 10 hours of aeration) amounted to only 50 mg/l or 5 per cent of the COD. After 10 hours of aeration the oxygen uptake rate was approximately 10 mg/l per hour, which is not an unusually high value for a suspended solids concentration of 2,500 mg/l. The rate also indicates that very little soluble BOD was left in the system at this time and that most of the 930 mg/l of COD consisted of material that was subject to chemical oxidation but apparently was not amenable to bacterial oxidation.

The effect of anti-foam on the ability of the organisms to utilize oxygen was shown to be negligible (Figure 7).

Figure 8 illustrates that high food concentrations stimulate rapid use of organic material. When the feed concentration was over 4,000 mg/l of COD, the oxygen uptake rate was approximately 100 mg of oxygen per liter per hour. At the time Warburg data were collected, the concentration of the feed for the laboratory unit was 22,000 mg/l, of which 72 ml were fed per day in 1.5 ml slugs each 30 minutes. Under these conditions the maximum amount of feed in the unit at any one time, which would be immediately after feeding, would be 8.2 mg/l of COD in addition to what remained from previous feeding cycles. From these data it is evident that the organisms would have no difficulty at all in removing this amount of organic material in 30 minutes.

Figure 9 shows that the mixed liquor developed in the field unit differed from the laboratory mixed liquor. The slow rate of oxygen uptake in the unfed field unit can be attributed to a smaller number of micro-organisms since the suspended solids data include both the weight of organisms and the weight of suspended fecal particles in the field unit. The low rate of oxygen uptake by the field mixed liquor under the stimulus of a high feed concentration can be partially explained by a low number of viable organisms in the system. It is also possible that the laboratory feed represented an unfamiliar source of organic material.

Figure 10 shows another example of a long lag period before rapid substrate utilization. Apparently, the bacterial population was not particularly well adapted to utilizing glucose and glutamic acid; however, once the organisms began to multiply the oxygen uptake rate increased rapidly. The value of 75 mg/l of BOD for the glucose-glutamic acid solution which had a COD of 153 mg/l is not surprising in view of previously reported results. Lee and Oswald (1954) reported a comparable Warburg BOD of 82 mg/l. The BOD determined on this glucose-glutamic acid solution by the dilution technique was 62 mg/l, which compared favorably to Lee and Oswald's value of 65 mg/l.

Although an oxygen uptake lag was demonstrated in the samples fed 72.8 and 182 mg/l COD (laboratory feed solution), this should not be interpreted

as a lack of viability of the micro-organisms in the mixed liquor. The rapid oxygen uptake exhibited when the seed was subjected to a feed concentration of 7, 280 mg/l COD attests to the seed viability.

10-Man Loading

Immediately upon increasing the feed to the simulated 10-man level the suspended solids concentration in the mixed liquor increased at a rapid and steady rate. After the solids reached the level of 12, 000 mg/l it was difficult to obtain a representative sample. In order to minimize this difficulty a large sample of mixed liquor was blended before an aliquot was taken. Although the accuracy of the suspended solids data might be questioned, the precision was sufficient to emphasize the apparent leveling trend exhibited by the mixed liquor suspended solids about the 200th day. Since the COD in a filtered sample of mixed liquor was not increasing at the end of the second period, nor had it increased at a sharp rate at any time during the period, and since the pH during the second 100 days was fairly steady (average 6.0), it was felt that a practical degree of equilibrium had been achieved. These results indicate that the system would have operated satisfactorily for the required six-month period at the loading of ten men. Additional support for this thesis is provided by the consideration that in a field installation much more dilution would be available from the initial charge of tap water, whereas in the laboratory unit the second feeding period was started with the tank filled with a liquid containing a high concentration of solids and COD.

In the laboratory, acceptable performance was indicated by lack of odors, by relatively low COD remaining in the filtered mixed liquor, and by the favorable degree of sedimentation provided.

15-Man Loading

In the prototype systems obviously a greater amount of water would be used for hand washing by 15 men than by 10 men. In the laboratory studies, however, the amount of water was held constant; that is, the theoretical detention time in the laboratory system was held constant. Since the simulated feed rate was increased to 15 men, the concentration of organics in the system was significantly increased. In this respect a true comparison with the so-called 10-man level for the previous period of testing is not possible. However, this could be considered as a test period in which water use was significantly reduced and the loading increased to that comparable to 15 men rather than 10 men. Under these conditions the laboratory system did not operate satisfactorily. The most interesting observations provided by this period of testing, in addition to showing that the laboratory unit could not adequately treat the simulated 15-man loading, were: (1) the increase in pH caused by organically overloading the system by aeration, and (2) the adjustment of pH at least temporarily relieving the odor problem. At the time of pH

adjustment feeding had been discontinued, and since the test was then terminated, it was not possible to determine the extent to which this problem would have been alleviated.

SECTION 7. CONCLUSIONS

1. The activated sludge method of waste disposal can be used to treat waste with a COD as high as 44,000 mg/1 (BOD - 21,000 mg/1) providing the treatment tank is large enough to provide sufficient aeration and dilution for the incoming waste.

2. The effluent contained a COD of approximately 1,500 mg/1; however, the BOD was much lower, and the rate of oxygen demand was low.

3. Although highly colored and turbid, the effluent can be used to serve as an acceptable flushing fluid in areas where water conservation is required.

4. The pH in the tank should be kept below 7.5 and preferably between 6 and 7 to prevent stripping of odor-causing ammonia.

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